Studies of Photon-Ion Interactions at ALS

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INTRODUCTION

Most of the known matter in the universe exists in the ionized plasma state, and the majority of the information that we have about the distant universe is carried to us by photons. Therefore a quantitative understanding of plasma opacities (the processes by which photons are emitted and reabsorbed by ions) is fundamental to astrophysics. The situation is similar for laser-produced plasmas in both inertial confinement fusion and XUV-photolithography research. A majority of photon opacities are currently based on theoretical calculations, and experimental benchmarks are few. Through the use of well-established accelerator technology, ion beams can be extracted from plasmas under highly controlled laboratory conditions. These ion beams are readily amenable to experimental study. Combining these techniques with emerging synchrotron technologies [1], such as undulator beamline 10.0 at ALS, affords a unique opportunity to study the interactions of photons with atomic and molecular ions found in the plasma state. New measurements may now be carried out that provide high-resolution spectroscopic data, resonance line-shapes, as well as absolute photoionization cross sections. In atomic and molecular physics, such data are needed for isolated ions in order to understand electron-electron interactions in complex, highly correlated systems. A new endstation for the study of ion-photon interactions at ALS is described. In addition, highlights are presented of two recent photoionization measurements; the first a study of metastable states of O^+, and the second involving measurements on Ne^+ at high spectral resolution.

EXPERIMENT

A schematic diagram of the endstation developed for the study of photon-ion interactions is shown in Fig. 1. Singly-charged ions are produced in a hot-filament discharge ion source, and accelerated to ion beam energies ranging from 5-15 keV. Following extraction, the primary ion beam is focused by a series of cylindrical electrostatic einzel lenses. Ionic species are selected using a 60º analyzing magnet with a mass-per-charge resolution of approximately100. The cross-sectional area of the ion beam is defined by two sets of adjustable beam slits mounted in the plane perpendicular to the ion beam velocity vector. After the ion beam has been selected and collimated, a set of 90º spherical-sector bending-plates merge the ion beam onto the axis of the counter-propagating photon beam from ALS beamline 10.0. The primary ion beam then enters a cylindrical interaction region which can be electrostatically biased to energy label the energy of photo-ions produced therein. In the center of the interaction region, the two-dimensional spatial overlap between the photon and ion beams is measured using a stepping-motor-driven slit scanner. Similarly, rotating-wire beam profile monitors are used at the beginning and end of the interaction region in order to ensure that the beams are well collimated along the entire interaction region. Fine positioning of the ion beam trajectory is achieved by two sets of mutually perpendicular electrostatic steering plates mounted immediately before the merging plates. The photon intensity is monitored using a calibrated Si p-n junction photodiode.

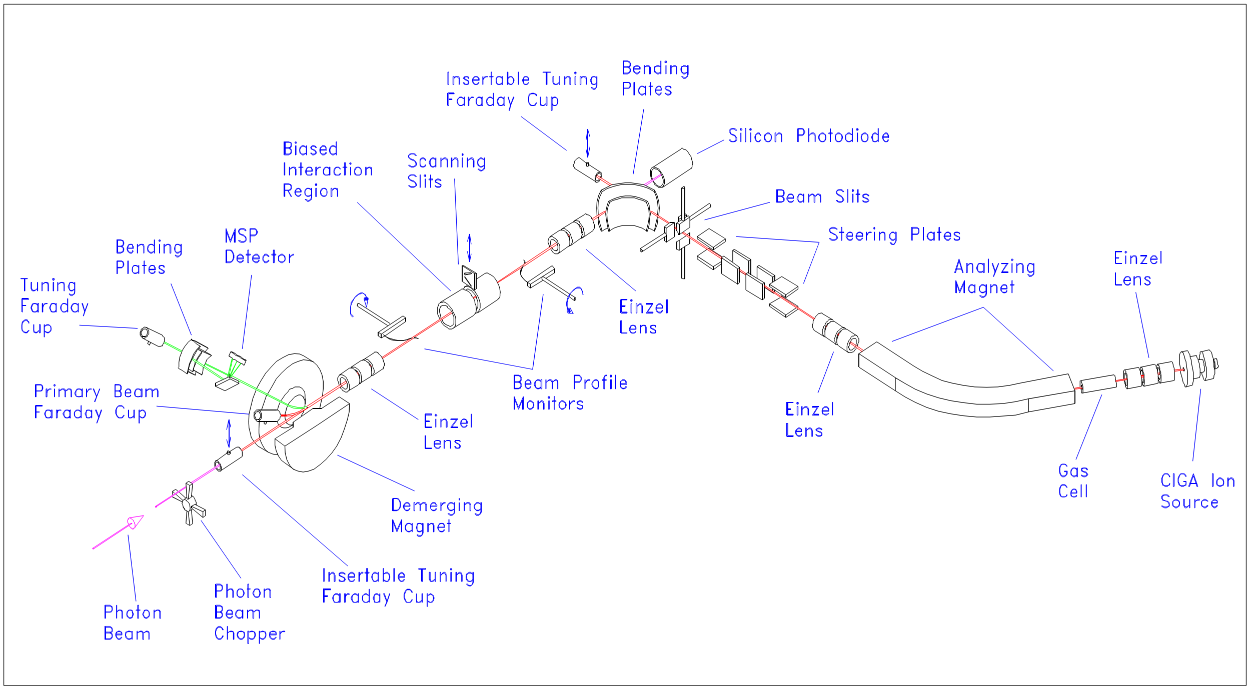

Figure 1. Ion-photon-beam (IPB) endstation installed at ALS beamline 10.0.

A second 45º analyzing magnet demerges the beams and disperses doubly-charged photo-ions produced in the interaction region from singly-charged ions in the primary beam. Following dispersion into the vertical plane, the interaction primary beam is collected in a Faraday cup, while the photo-ions pass through a hole in the back of the cup. The primary ion beam current is monitored for normalization of the photo-ion yield. The photo-ion beam enters another set of 90º spherical-sector bending-plates that deflect the beam out of the vertical dispersion plane and help to minimize background counts associated with the collection of the primary ion beam. Thereafter, the photo-ions enter a negatively-biased detection box, wherein the ions impinge upon a stainless steel plate and produce secondary electrons, which are in turn accelerated towards a microspherical plate single-particle detector with a positively-biased anode. It should be noted that doubly-charged ions are also produced in collisions between the fast-moving ions in the primary beam and residual gas molecules in the ultra-high vacuum system. Hence, it is necessary to chop the photon beam in order to subtract this background.

RESULTS

Photoionization measurements on O^+ were made over a broad photon energy range (29-51 eV). A photo-ion yield spectrum taken in the photon energy range near the O^{2+} ionization threshold is shown in Fig. 2. This spectrum was taken with a nominal photon energy resolution of 25 meV. The resonance features below the O^+ ($2s^22p^3$ ^4S) ground state threshold at 35.12 eV correspond to photoionization from the O^+ ($2s^22p^3$ ^2D and ^2P) long-lived metastable states. O^+ metastable ions are ubiquitous in nature, and account for 60% of the total ion beam current. The metastable fraction was determined by passing the O^+ ion beam through a nitrogen-filled gas cell placed at the output of the ion source. The metastable components of the O^+ beam undergo a resonant charge transfer process with the N_2 gas molecules and are neutralized [2]. In contrast, charge transfer with the ^4S ground state is non-resonant. Therefore, it is possible to readily attenuate the metastable ions and to determine their population in the beam. Also shown in Fig. 2 are the results of recent R-matrix calculations of cross sections for photoionization from the ^2D and ^2P

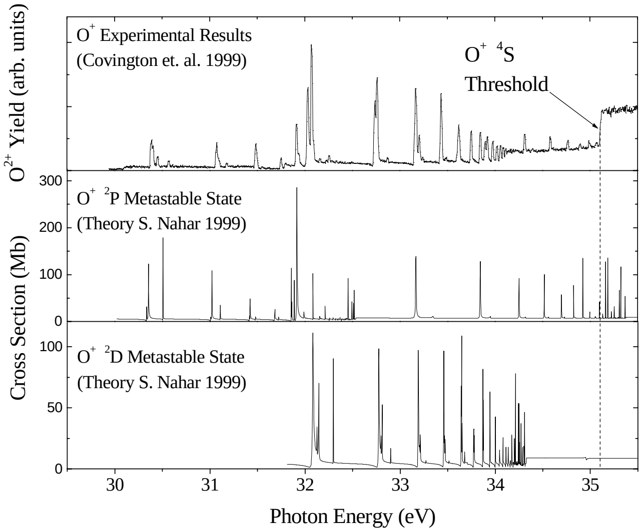

Fig. 2. Near-threshold photoionization of O^+.

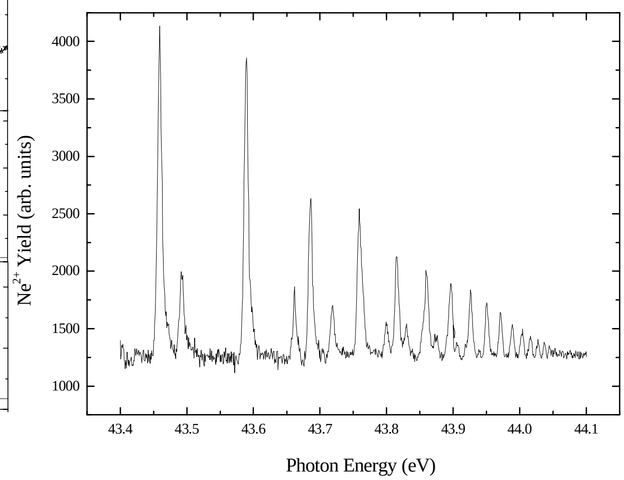

Fig. 3. Photoionization of Ne^+ with ΔE = 7.5 meV.

metastable states [3]. Shown in Fig. 3 is a photo-ion yield spectrum for the photoionization of Ne^+ at photon energies just below to the Ne^{2+} (^1D) ionization threshold (44.167 eV). At least two Rydberg series are evident in the spectrum, and are assigned to the Ne^+ $2p^4(^1D)$ $n\ell$ autoionizing resonances [4]. The metastable states of Ne^+ all have lifetimes of less than 100 ns, so the beam is comprised of ground state ions only in this case [5]. This spectrum was taken with a nominal photon energy resolution of 7.5 meV, a demonstration of the high-resolution capabilities of the ion-photon-beam endstation at ALS beamline 10.0. Line-widths of several individual resonances have been measured at a nominal resolution of 1 meV. Comparisons with predictions of a recent 28-state R-matrix calculation [6] indicate that spin-orbit coupling may be required to reproduce all of the experimentally observed resonance features. Absolute photoionization cross section measurements have also been completed for both O^+ and Ne^+.

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